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Optical Responses of Josephson Vortex flow Transistor under irradiation of femtosecond laser pulses

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1. Introduction

Recent explosive increase of digital data requires a larg-capacity and high-speed communication system. Single-flux-quantum (SFQ) logic circuits are expected as a network device such as a high-end router and a server, because these are operative at a clock rate above 100GHz in principle [1]. As the sophisticated SFQ circuits being realized, an interface between conventional electronic systems at room temperature and the SFQ circuits at cryogenic temperatures is becoming a bottleneck for the high speed operation, because both of the large signal loss and impedance mismatch between them are inevitable at such a high clock rate. As one of the approaches to solve the problems, we have developed an optical interface that can convert optical signals to SFQ signals. The optical interface, if realized, may bring break-through for the ultra-high speed data processing with SFQ circuits. Up to the present, however, only a few groups have challenged the target [2, 3].

Vortex flow transistors (VFTs) based on the motion of vortices in superconducting thin films or Josephson junctions had been expected as high-speed three terminal devices for superconducting circuits. However, few studies on VFTs have been performed in recent years. The main reason for this fact is that it is difficult to achieve both a significant signal gain and a high operation speed. Recently, we have considered applying VFTs to an input interface for a single flux quantum (SFQ) logic circuit, which converts electrical or optical signals to flux quanta [4, 5]. In this case, high-speed operation over the several tens GHz is required, however, the large power gain is not necessary for this type of interface because the electrical or optical signals widely used are considerably larger than SFQ signals. VFT differs from conventional DC/SFQ circuit, and can control flux quanta with the external magnetic field independent from the input signals. Therefore, various types of input signals are acceptable by modifying the signals with the external field. Moreover, VFTs can operate as a multiplier by inputting different signals to the control line and the flow channel.

In this report, we have fabricated Josephson vortex flow transistors (JVFTs) and experimentally verified the characteristics of JVFTs from the responses to the electrical input signals, and subsequently observed the optical response of JVFTs under the irradiation of femtosecond laser pulses.

2. Experimental Results

Josephson junctions were prepared using c-axis oriented 100 nm thick YBCO thin films grown on 24◦ bi-crystal MgO (100) substrates. Au layer was deposited by RF sputtering as contact pads and as well as a protection layer from laser irradiation. The pattering of the JVFTs was performed by conventional photolithography and Ar ion beam etching. Figure 1 shows the micrograph of the active region of fabricated JVFT. The YBCO thin film is covered by the Au film except for the flux flow channel consist of parallel array of Josephson junctions indicated with dotted

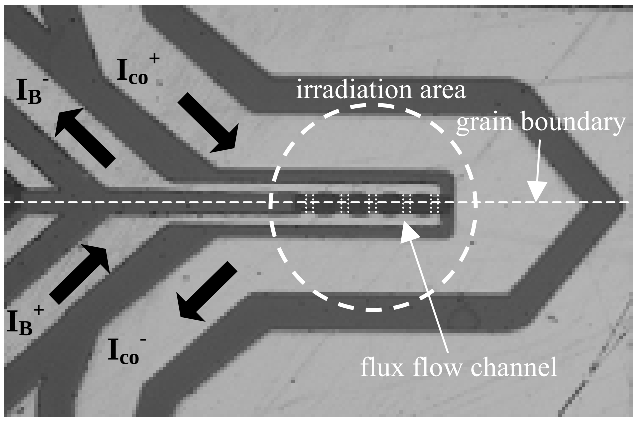

Fig. 1 The micrograph of the active region of Josephson vortex flow transistor.

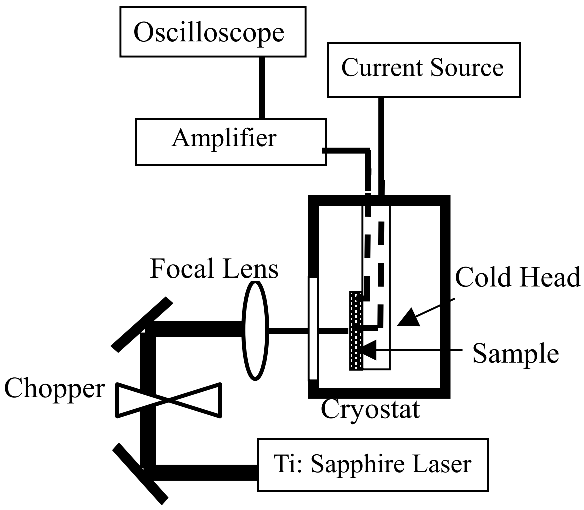

Fig. 2 A schematic diagram of measurement system of the optical response of JVFT

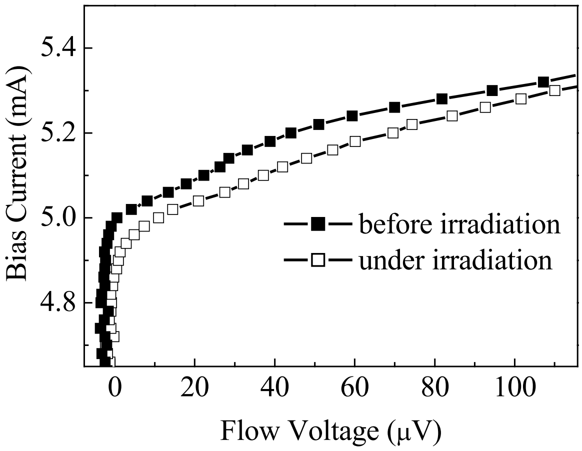

Fig. 3 I_B-V_f characteristics of the JVFT before and after the laser irradiation with the power of 8 mW at the temperature of 17K.

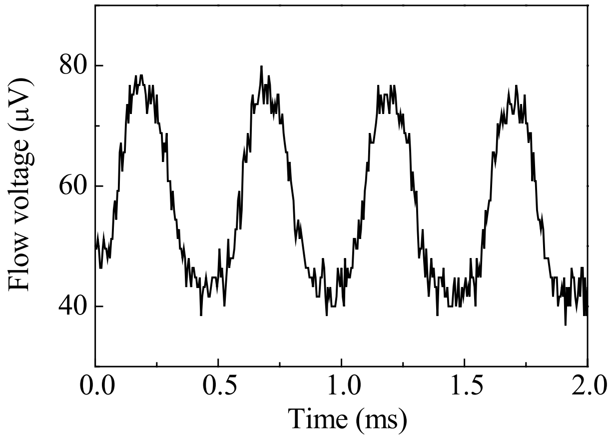

Fig. 4 The response of flow voltage V_f under the irradiation of laser pulses with chopping rate of 2 kHz.

lines in the figure. The width of Josephson junctions is 3 μm, and each loop area is 10×8 μm^2. The center dashed line indicates the grain boundary of the MgO substrate. The control current line with the width of 15 μm is located 5 μm apart from the edge of the channel. The bias current flows from terminal I_B^+ to I_B^-, and the control current flows from terminal I_{co}^+ to I_{co}^-. The mode locked Ti:sapphire laser (wavelength: 800 nm, pulse width: 100 fs, repetition rate: 82 MHz) was used for laser irradiation. The dashed circle in Fig. 1 shows the laser spot and includes the flux flow channel and the control line, however, only the channel was irradiated with the laser pulses because the protected Au layer covers the other part of the YBCO thin film. Figure 2 shows a schematic diagram of the measurement system used in this study. The devices were mounted on the cold finger in the GM type cryostat in which the temperature was controlled with a resistive heater and thermocouples from 10 K to room temperature. Input signals that flow in the control line were generated by a function generator. Femtosecond pulsed laser was modulated by a optical chopper and focused to the flow channel. The control current I_{co} and the output voltage V_f was observed with a digital oscilloscope.

Figure 3 shows the I_B-V_f characteristics before and after the laser irradiation with the power of 8 mW at the temperature of 17K. The increase of the flow voltage by the laser irradiation was observed.

Figure 4 shows the response of flow voltage V_f under the irradiation of laser pulses with chopping rate of 2 kHz. The modulation of V_f at 2 kHz is clearly observed. The irradiated laser power is about 8 mW. The amplitude of the modulation is 16 ~ 18 μV and almost constant to the variation of the chopping rate.

These results are explained as below. Cooper pairs in the Josephson junctions are excited by the laser pulses and the junctions shift to normal state. From our previous research, it is confirmed that the superconductivity recovered in about 1 ps, therefore, this device have feasibility to operate above several hundred GHz.

3. Conclusions

We have fabricated a Josephson vortex flow transistor with YBCO thin films, and observed optical responses under the irradiation of femtosecond laser pulses to the vortex flow channel. As a result, clear modulation of output voltage was observed, which indicate that the motion of vortex could be controlled by laser pulses.

Acknowledgements

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References

[1] K. K. Likharev and V. K. Sememov, IEEE Trans. Appl. Supercond, **1** (1991) 3.
[2] C-C. Wang, M. Currie, D. Jacobs-Perkins, M. J. Feldman, R. Sobolewski, and T. Y. Hsiang, Appl. Phys. Lett. **66** (1995) 3325.
[3] R. Adam, M. Currie, C. Williams, R. Sobolewski, O. Harmack, and M. Darula, Appl. Phys. Lett. **76** (2000) 496..
[4] Y. Doda, T. Kiwa, I. Kawayama, H. Murakami and M. Tonouchi, Physica C **392-396** (2003) 1504.
[5] Y. Doda, T. Kiwa, I. Kawayama, H. Murakam, and M. Tonouchi, Chinese Journal Physics **42** (2004) 458.